Multi-Step Ka/Ka Dichroic Plate with Rounded Corners for NASA's 34m Beam Waveguide Antenna

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***Abstract*— A multi-step Ka/Ka dichroic plate Frequency Selective Surface (FSS structure) is designed, manufactured and tested for use in NASA's Deep Space Network (DSN) 34m Beam Waveguide (BWG) antennas. The proposed design allows ease of manufacturing and ability to handle the increased transmit power (reflected off the FSS) of the DSN BWG antennas from 20kW to 100 kW. The dichroic is designed using HFSS and results agree well with measured data considering the manufacturing tolerances that could be achieved on the dichroic.**

I. Introduction

DSN BWG antennas employ various transmit/receive configurations to support Uplink (UL) and Downlink (DL) communications with many operational spacecraft. This involves employing dichroic plates (see [1]) to ensure simultaneous operation in different frequency bands. The DSN has a plan to support the Juno and BepiColombo spacecraft with simultaneous Ka-band UL/DL operation. This requires a Ka/Ka dichroic installed above an existing X/X/Ka feed configuration as presented in [2]. DSN's Ka-band UL/DL frequencies are closely located and centered at 34.45 (UL) and 32.05 GHz (DL) each with 500 MHz bandwidth. In our design, a multi-step dichroic plate provides a waveguide path that reflects the DL frequency while passing the UL frequency.

An existing Ka/Ka dichroic plate with small perforated area is currently being operated at DSN BWG antennas. It has five layers and sharp edge rectangular apertures. It requires use of a wire EDM technique during fabrication. Due to different beam waveguide optics, the new dichroic will have about 3.5 times larger perforated area. However, the wire EDM technique is not suitable for a very large number of holes because of the very high cost and long fabrication time.

This paper presents the new design of the Ka/Ka dichroic that will drastically reduce fabrication cost and time. The new dichroic has rounded corners in the hole patterns. The curvature at each corner must be large enough so that a faster and lower cost milling technique can be used. In addition to Ka/Ka operation the new dichroic will be illuminated in the near-field using a 100kW X-Band transmitter motivating the new design to reduce the number of joints and hence the possibility of arcing.

II. Design Methodology

Design presented here resembles the one presented in [3] which satisfies a 30^{o} angle of incidence commonly used in 34m antenna BWG configurations shown in [1]. The thick multi-layer design is employed to reduce transmission through the FSS in the receive band to very low levels required in the ultra-low noise Ka-band receive system, while passing the 1 kW Ka band uplink through the FSS. However, the design in [3] requires sharp corners in the waveguide structure which makes the manufacturing of the plate at this frequency both costly and time consuming due to the wire EDM process. To remove sharp corners from the design, a method was proposed in [4] that was later applied to a rounded straight through waveguide FSS structure. To design this multi-step FSS structure, we found that HFSS [5] can efficiently handle arbitrarily shaped apertures as well as the multiple layers presented here. In HFSS, we assumed infinitely extended periodic structures even though the plate is illuminated by the feed at various incident angles close to 30^{o}. Appropriate master/slave boundary conditions on the unit cell as well as assigning enough Floquet modes at each port were used to ensure computational convergence.

Before starting the design, practical values for waveguide radii that can be comfortably machined were specified by the fabricator, as shown in Figure 1. The structure in [3] was scaled to shift its operating frequency to the Juno's spacecraft's band centered at 34.37 GHz. Consequently, the structure in Figure 1 is simulated in HFSS with the manufacturer's recommended fillets radii. Nine design parameters accounting for width, height and length of inner and outer waveguides as well as waveguide wall thickness are used in our design space. Design parameters are varied to achieve reflection and transmission coefficients at the desired UL and DL Ka-band frequencies.

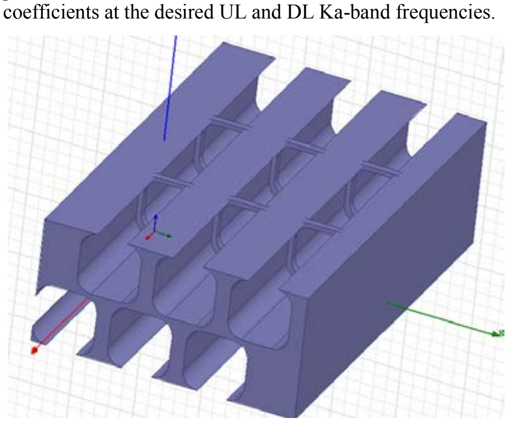

Figure 1: Multi-step dichroic model in HFSS. Only a unit cell is used in the calculations. Drawing is not to scale.

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III. MANUFACTURING THE DICHROIC PLATE

The dichroic plate was fabricated at Custom Microwave, Inc (CMI). For ease of manufacturing, the plate is made of two identical layers by dividing the plate half way in cavity region. Adequate flatness and enough compression between mating plates is incorporated to ensure sufficient contact between layers to avoid high power arcing.

IV. CALCULATED AND MEASURED DATA

Calculated vs. measured reflection coefficients are shown in Figure 2 and Figure 3 which correspond to Transverse Electric (TE) and Transverse Magnetic (TM) incident and reflected fields on the dichroic plate at a 30^o angle of incidence. To verify the analysis, two independent measurements, one at CMI and one at JPL, were taken and are shown along with the simulation data. Calculated and measured reflection coefficients show some differences including a 150 MHz shift between them which correspond to variations in the manufactured part based on dimensional tolerances. A simulation of one possible dimensional variation is shown in Figure 2 and Figure 3 verifying that the 150 MHz frequency shift is within the manufacturer tolerance. Also the TE and TM reflection coefficient is somewhat higher than what is predicted. Sources of error include the feed illumination which spans roughly $+/-10^o$ from the 30^o plane wave assumption as well as manufactured dimensional variations. Nevertheless the measurement is within the spec for the required reflection at the UL transmit band near 34.37 GHz. The Reflection coefficients at the 32.05 GHz DL bands also satisfy the electrical requirement for the dichroic.

It should be noted that the dichroic will be illuminated by a Circularly Polarized (CP) field. It can be shown that CP reflected power is the average of TE and TM powers plotted in Figures 2 and 3. Consequently, the overall reflection coefficient for the plate at CP (not shown in this paper) is somewhat better than what is shown for the TE and TM incident field.

In addition, a 100kW high power X-Band signal was successfully reflected off the 5-layer plate reported in [2] with minimal arcing since the newly designed plate was not available at that time. This assured us that the new plate will with only a single joint, will operate successfully with the same incident power.

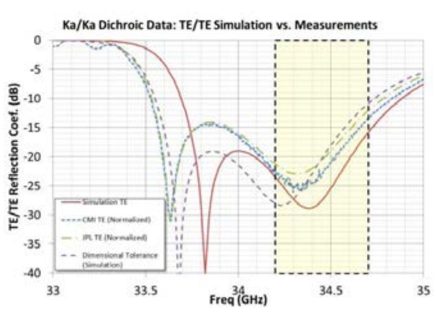

Figure 2: Comparison between calculated and measured reflection coefficient due to an incident TE field

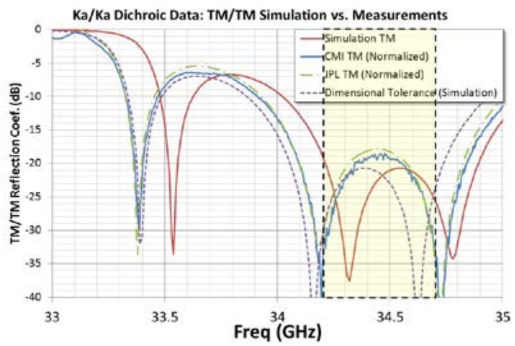

Figure 3: Comparison between calculated and measured reflection coefficient due to an incident TM field

V. CONCLUSION

A multi-step Ka/Ka dichroic plate is designed for NASA's 34m BWG antenna passing UL and reflecting DL DSN Ka-band frequencies. The dichroic plate is to handle 100kW of near-field X-Band transmit power as well, and it is designed with rounded corners in a waveguide structure to avoid costly wire EDM process.

Adequate margins were placed in the design in to order to pass electrical spec with allowable manufacturing tolerances. Measured and calculated performance of the dichroic plate show reasonable agreement considering manufacturing dimensional tolerances as well as computational assumptions.

ACKNOWLEDGEMENT

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